

A measurement of the rate of wrong-sign decays $D^0 \rightarrow K^+ \pi^-$

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Abstract

A D^0 meson can decay to $K^+\pi^-$ through doubly Cabibbo-suppressed decay or via $D^0 - \bar{D}^0$ mixing. With 46.2 fb^{-1} of integrated luminosity collected by Belle, we have measured the time integrated rate of the wrong-sign process $D^0 \rightarrow K^+\pi^-$ relative to that of the Cabibbo-favored process $D^0 \rightarrow K^-\pi^+$ to be $R_{WS} = (0.372 \pm 0.025^{+0.009}_{-0.014})\%$ (preliminary). The $D^0 - \bar{D}^0$ mixing parameters can be derived from the time distribution of the wrong-sign process.

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I. INTRODUCTION

The Standard Model predicts that $D^0 - \bar{D}^0$ mixing is small, with many estimates for the mixing parameters $x = \Delta M/\Gamma$ and $y = \Delta\Gamma/2\Gamma$ at the $\lesssim 10^{-3}$ level, although long-distance effects in the Standard Model may raise both parameters to $\sim 10^{-2}$ [1, 2]. New physics effects may enhance x , but are not expected to affect y . Consequently, a discovery of large x with small y would imply new physics.

Experimentally, mixing can be identified by the study of the wrong-sign (WS) process $D^0 \rightarrow K^+ \pi^-$, which can proceed directly through doubly Cabibbo-suppressed decay (DCSD) or through mixing followed by Cabibbo-favored decay (CFD). The decay of an initial $D^{*+} \rightarrow D^0 \pi_s^+$ yields a charged “slow” pion, denoted π_s^+ , whose sign can be used to tag the initial D as either D^0 or \bar{D}^0 .

The differential WS rate relative to the right-sign process is [3]

$$\begin{aligned} r_{WS}(t) &= \frac{\Gamma(D^0(t) \rightarrow K^+ \pi^-)}{\Gamma(D^0 \rightarrow K^- \pi^+)} \\ &= \left[R_D + \sqrt{R_D} y' \Gamma t + \frac{1}{4} (x'^2 + y'^2) \Gamma^2 t^2 \right] e^{-\Gamma t}, \end{aligned} \quad (1)$$

where R_D is the relative rate of DCSD to CFD. We use the convention of CLEO [7], with $y' = y \cos \delta - x \sin \delta$ and $x' = x \cos \delta + y \sin \delta$, where δ is the relative strong phase between the DCSD and CFD channels. A fit to the $r_{WS}(t)$ distribution in Belle data, to obtain the mixing parameters, is underway. In this paper, we present a preliminary measurement of the time-integrated wrong-sign rate,

$$R_{WS} = R_D + \sqrt{R_D} y' + \frac{1}{2} (x'^2 + y'^2), \quad (2)$$

based on the same event reconstruction and background-handling techniques used for the full analysis.

II. EXPERIMENTAL APPARATUS AND DATA SAMPLE

The analysis is based on data accumulated by the Belle detector at KEKB [4], an asymmetric collider with 8 GeV electron and 3.5 GeV positron storage rings. The data set corresponds to an integrated luminosity of 46.2 fb^{-1} .

Belle [5] is a general-purpose detector based on a 1.5 T superconducting solenoid. Charged tracks are reconstructed using a 50-layer Central Drift Chamber (CDC) and a 3-layer double sided Silicon Vertex Detector (SVD). Particle identification for charged kaons and pions is performed by combining information from the CDC (dE/dx), a set of time-of-flight counters (TOF) and a set of aerogel Čerenkov counters (ACC). The combined result of the three systems provides K/π separation up to 3.5 GeV.

III. CANDIDATE RECONSTRUCTION

For $D^0 \rightarrow K^+ \pi^-$ decay, we use oppositely charged tracks where both tracks have good SVD hits. Charged K and π mesons are required to be positively identified, with efficiencies

88.0% and 88.5% respectively, and fake rates of 8.5% (π fakes K) and 8.8% (K fakes π). D^{*+} candidates are then reconstructed by combining the D^0 candidate with another charged track, π_s^+ . The reconstructed D^{*+} momentum in the center of mass frame $P^*(D^*)$ is required to be greater than 2.5 GeV to eliminate $B\bar{B}$ events. Vertex fits are performed, requiring the two tracks forming the D^0 candidate to originate from a common vertex, the D^0 flight direction to be consistent with a particle originating from the interaction point, and the π_s^+ to originate from the D^0 production vertex. We accept candidates with good vertex quality. The value of D^0 mass M and the energy released in D^{*+} decay $Q = M(K^+, \pi^-, \pi_s^+) - M(K^+, \pi^-) - M(\pi_s^+)$ are then obtained.

The right-sign decay $D^{*+} \rightarrow D^0\pi_s^+$, $D^0 \rightarrow K^-\pi^+$ is reconstructed in the same way. Here and throughout this paper, the inclusion of charge conjugate modes is implied.

IV. BACKGROUND DETERMINATION

The information in the signal region alone is insufficient to determine the signal time distribution, because the background level is comparable to the signal in the signal box, and the various backgrounds have different time distributions. We therefore divide the background into categories, and determine the population of each using M, Q information. To obtain the signal yield as well as the level of each background, we perform a two-dimensional (2D) fit to (M, Q) . By studying a large number of continuum Monte-Carlo (MC) events, we categorize the backgrounds as follows:

- $D^0 \rightarrow K^-\pi^+$ with double misidentification ($K^- \rightarrow \pi^-, \pi^+ \rightarrow K^+$).
- $D^0 \rightarrow K^+K^-$ with single misidentification ($K^- \rightarrow \pi^-$).
- $D^0 \rightarrow \pi^+\pi^-$ with single misidentification ($\pi^+ \rightarrow K^+$).
- $\bar{D}^0 \rightarrow K^+\pi^-$ combines with a random slow π^+ to form a fake D^{*+} .
- $D^0 \geq 3$ body decay, with two daughters identified as K, π .
- D^+, D_s^+ decay, with two daughters identified as K, π .
- Pure combinatorial background.

The $D^0 \rightarrow K^-\pi^+$ double misidentification background can be rejected by kinematic requirements. We evaluate the D^0 mass under swapped mass assignment $M_{\text{flip}} = M_{K \rightarrow \pi, \pi \rightarrow K}$. If M_{flip} falls within 28 MeV ($\sim 4\sigma$) of the nominal D^0 mass, the $D^0 \rightarrow K^+\pi^-$ candidate is rejected. For the $D^0 \rightarrow K^+K^-, \pi^+\pi^-$ single misidentification background, the change from the hypothesis that a charged track is a $\pi(K)$ to a $K(\pi)$ in the D^0 2 body decay daughters results in an increase(decrease) in the reconstructed D^0 mass M of at least 60 MeV. This behavior has been studied in both data and MC. So we choose the D^0 mass window $1.81 \sim 1.91$ GeV for histogram making and fitting to exclude these two backgrounds.

Each of the remaining four types of background is parametrized and fitted with a 2D function to obtain its shape, as shown in Figs 1–4. The backgrounds in the right-sign sample are categorized and fitted in a similar way. They are grouped into three types:

- $D^0 \rightarrow K^-\pi^+$ combines with a random slow π^+ to form a fake D^{*+} .

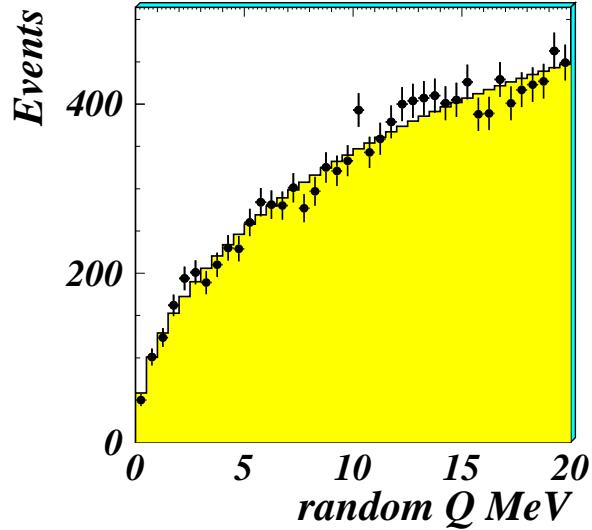


FIG. 1: The Q distribution for MC events (points) and the fit function (histogram) for the random slow π^+ background. The M shape is fixed to that of the right-sign D^0 signal in the data.

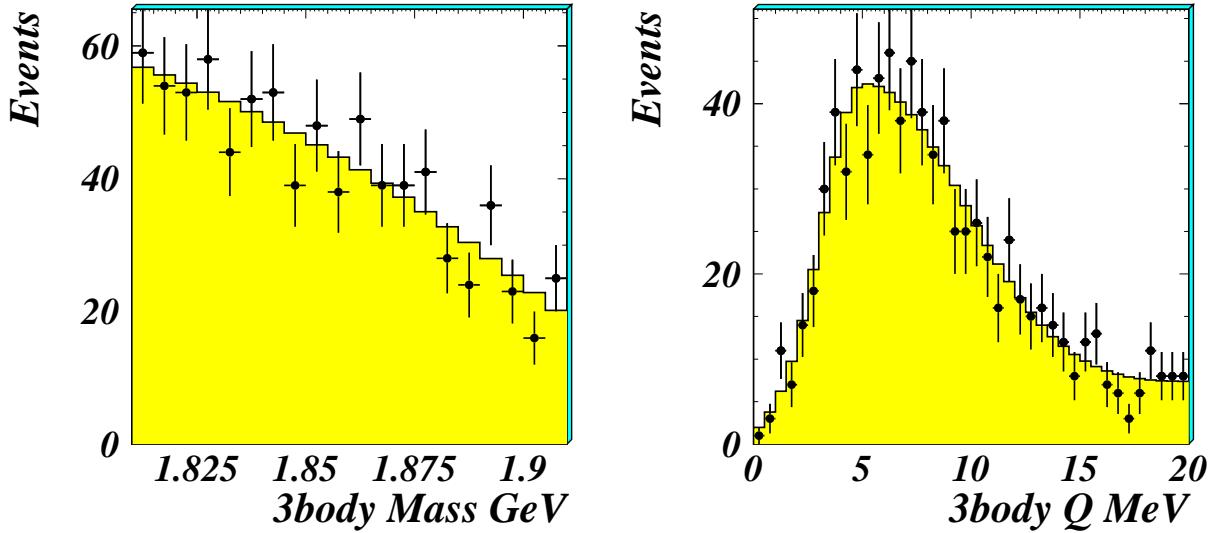


FIG. 2: M (left) and Q (right) distributions for MC events (points) and the fit functions (histograms) for the $D^0 \geq 3$ body background.

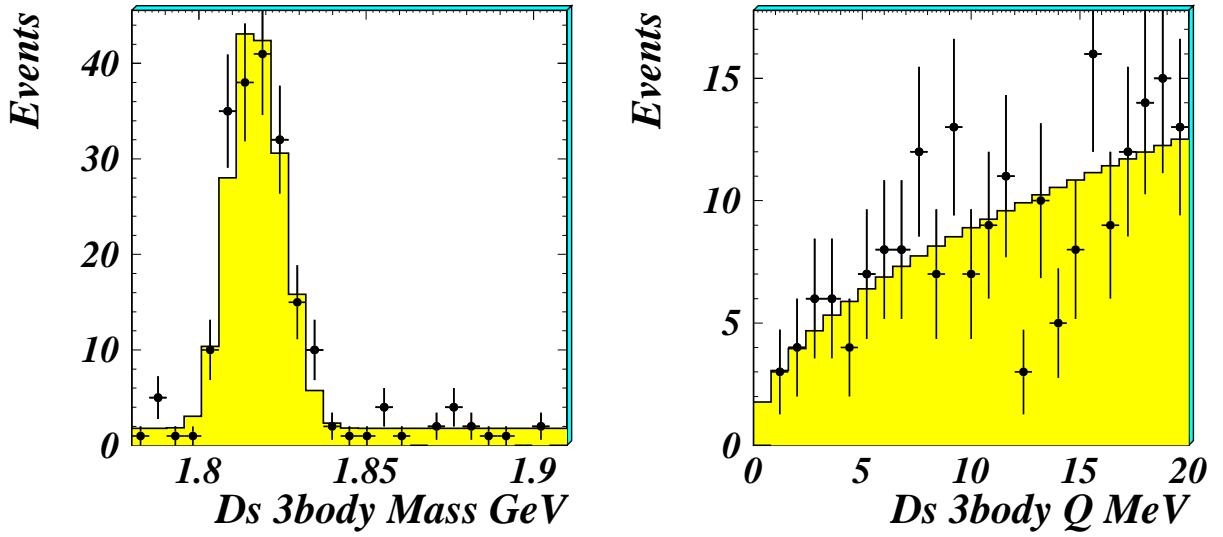


FIG. 3: M (left) and Q (right) distributions for MC events (points) and the fit functions (histograms) for the D_s^+, D^+ background.

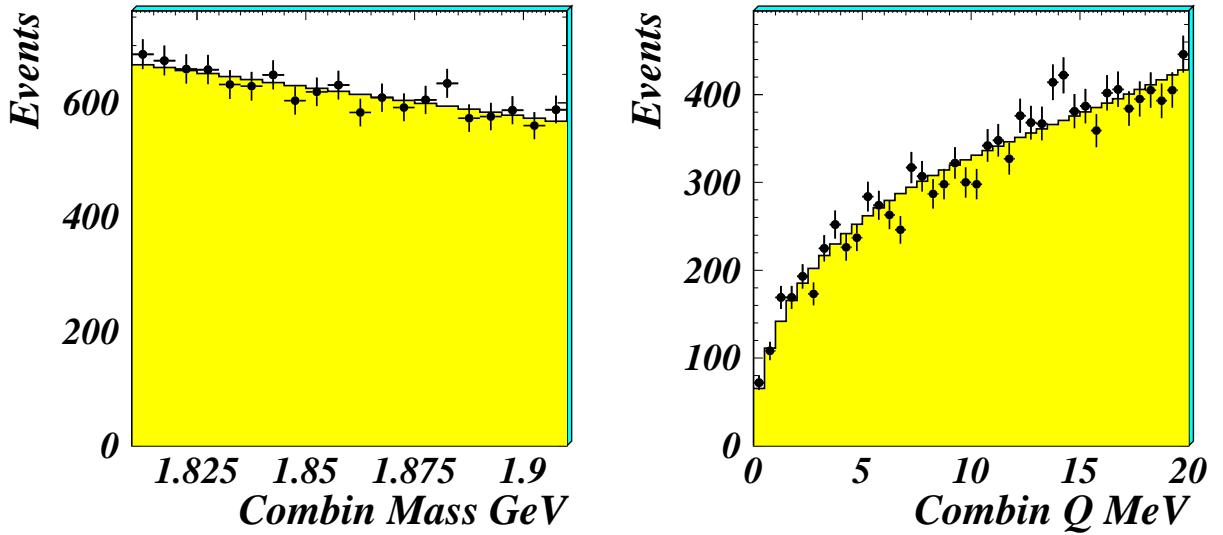


FIG. 4: M (left) and Q (right) distributions for MC events (points) and the fit functions (histograms) for the combinatorial background.

- Charmed ground state meson ≥ 3 body decay, with two daughters identified as K, π (“ $D \geq 3$ body” background).
- Pure combinatorial background.

V. RESULTS

We perform a 2D fit to the (M, Q) distribution for the right-sign data, with the normalization of each background allowed to float in the fit. The signal is represented by a double Gaussian in M and a bifurcated Student’s t function in Q . The projections onto M and Q are shown in Fig. 5. To perform the 2D fit for the wrong-sign data, we fix the wrong-sign signal shape to the shape of the right-sign signal, and float the normalization of the signal and each type of background, but fix the *relative* normalization between the D_s^+, D^+ and $D^0 \geq 3$ body backgrounds. The projections of the wrong-sign data and the fit results are shown in Fig. 6. The data are the circles with error bars, and there are 20 bins in M ($1.81 \sim 1.91$ GeV) and 160 bins in Q ($0 \sim 20$ MeV). We find 120795 ± 371 $D^0 \rightarrow K^- \pi^+$ and 450 ± 31 $D^0 \rightarrow K^+ \pi^-$ events. The ratio R_{WS} is then calculated to be $(0.372 \pm 0.025)\%$.

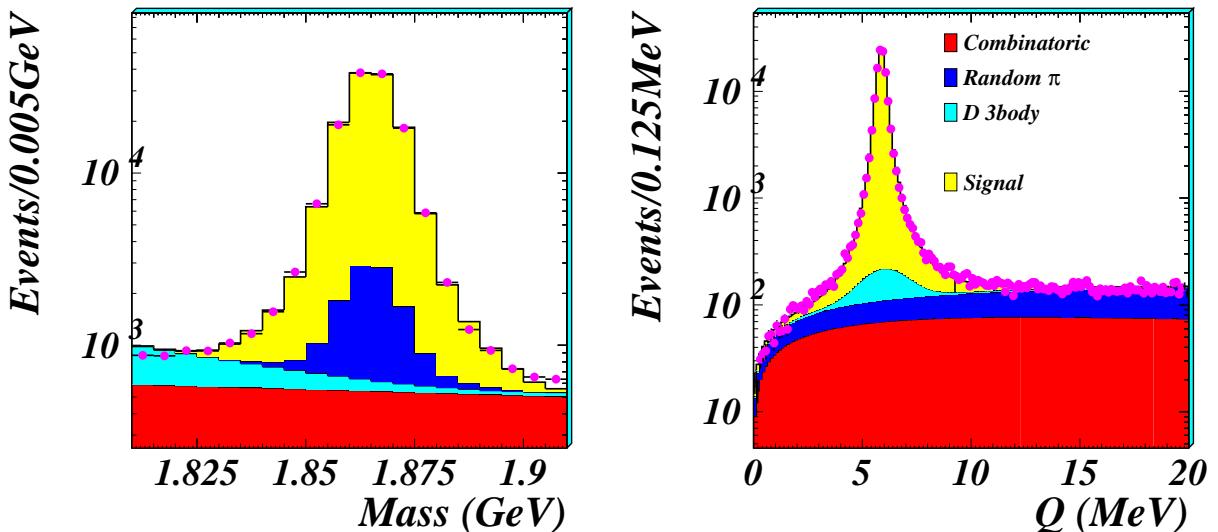


FIG. 5: Projections of M (left) and Q (right) for the right-sign data (points) and the fit functions (histograms), for the region $1.81 \leq M < 1.91$ GeV and $0 \leq Q < 20$ MeV. Note the logarithmic scale.

Many systematics cancel because R_{WS} is a ratio between two decay modes with similar kinematics. The dominant systematic errors stem from potential imperfect modeling of the shapes for our backgrounds. We vary selection criteria (K and π identification cuts, vertexing criteria, the $P^*(D^*)$ cut) and use different background parameterizations, and then repeat the fit on each category of MC background as well as on the right-sign and wrong-sign data. The variation in the result is taken as a measure of the systematic error. We also vary the background shape parameters according to their errors and calculate the resulting error on

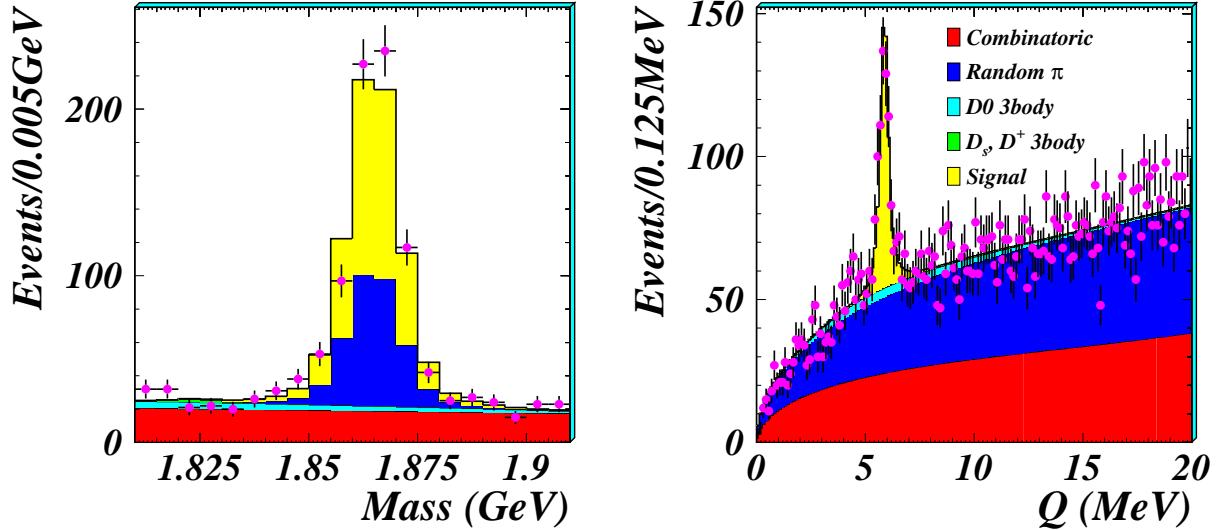


FIG. 6: Projections of M (left) and Q (right) for the wrong-sign data (points) and the fit functions (histograms), within a 3σ window in the complementary variable ($5.27 \leq Q < 6.47$ MeV and $1.8445 \leq M < 1.8845$ GeV respectively). The signal contribution is shaded yellow.

TABLE I: Summary of systematic errors on R_{WS}

Source	Systematic error(%)
Kaon identification	+0.0067 -0.0023
Pion identification	+0.0023 -0.0048
Vertex fit	+0.0042 -0.0051
$P^*(D^*)$ cutoff	+0.0000 -0.0117
Background shapes	+0.0027 -0.0026
Background parametrizations	± 0.0011
Total	+0.009 -0.014

R_{WS} . The correlations among these background shape parameters are considered either in the variation or in the R_{WS} error calculation. The results are summarized in Table I. All systematic errors are combined in quadrature.

In summary, we have measured the ratio R_{WS} of the rate of the wrong-sign process $D^0 \rightarrow K^+\pi^-$ relative to the right-sign process $D^0 \rightarrow K^-\pi^+$ to be

$$R_{WS} = (0.372 \pm 0.025(\text{stat})^{+0.009}_{-0.014}(\text{syst})) \%. \quad (3)$$

This result is preliminary. It is compared with other experimental results [6, 7, 8, 9] in Fig 7.

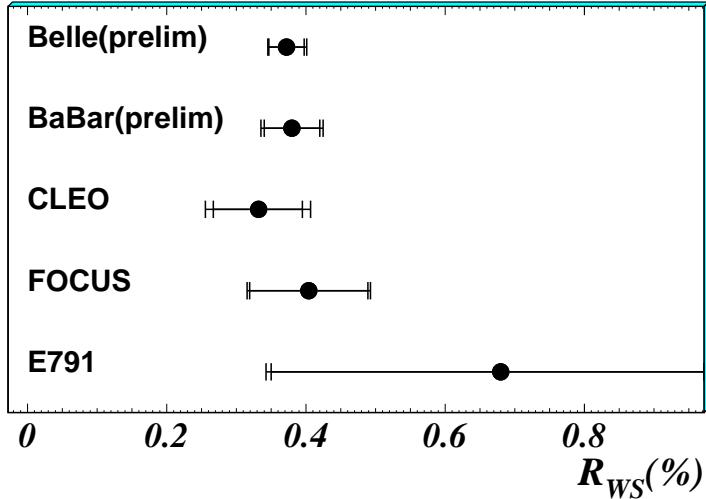


FIG. 7: Various experimental results for R_{WS} .

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